Consortium for Electric Reliability Technology Solutions

Research Overview

LBNL Physics Division

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Electric Grid Problems are Costly

- **Blackouts** – 2003 Northeast Blackout cost $5-10 billion
- **Congestion**
  - Annual cost estimated to be several billion dollars
  - DOE's 2006 National Electric Transmission Congestion Study indicated that "transmission congestion always has a cost."
- **Market Dysfunction** – 2001 California electricity crises cost California consumers billions of dollars
- **Power Quality and Reliability** – Inadequate power quality and reliability costs businesses $50 to $100 billion annually
- **Market Inefficiency** – Higher LMP, redispatch, and market power result in higher consumer costs

Need Transmission Investments – Upgrade Existing Grid, Expand Infrastructure, Research and Demonstrate New Technologies, and Modernize Grid with Monitoring, Visualization, and Digital Technologies

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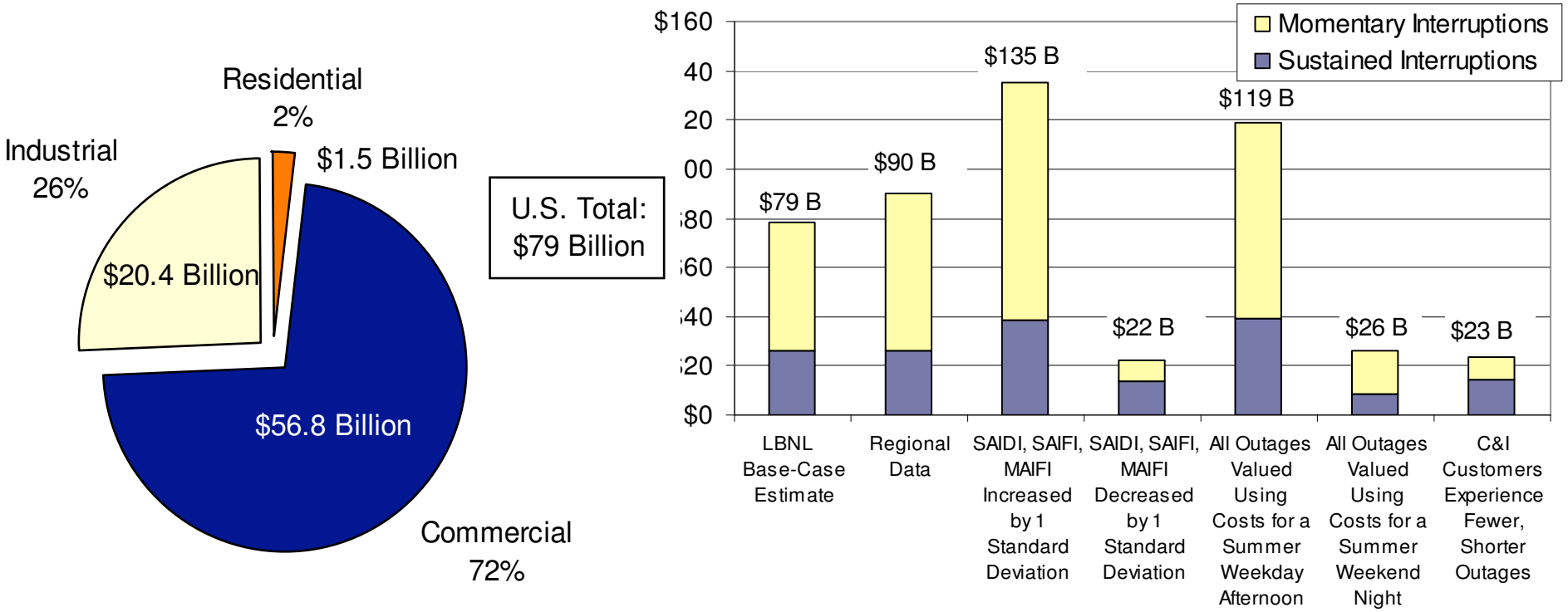
In 2004, LBNL Estimated That Power Interruptions Cost the Nation ~$79 B/yr

Yet, LBNL Also Found Significant Uncertainties in the Data



Source: Hamachi-LaCommare, K, and J. Eto. *Understanding the Cost of Power Interruptions to U.S. Electricity Customers.* July, 2004. LBNL-55718
http://certs.lbl.gov/certs-rtina-pubs.html

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- CERTS was organized in 1999 as a partnership among universities, the private sector, and Department of Energy national labs. Consortium includes four labs (Lawrence Berkeley, Oak Ridge, Sandia, Pacific Northwest), Power Systems Engineering Research Center (consortium of universities led by Arizona State), and Electric Power Group.
- CERTS Industry Advisory Board includes ISOs, utilities, regulators, generators.
- CERTS research leverages public and private resources, including funding by the Department of Energy, Office of Electricity Delivery and Energy Reliability, Transmission Reliability Program, and the California Energy Commission, Public Interest Energy Research Program.
- CERTS research is focused on addressing gaps in tools, technologies, systems, market rules, and management processes needed to manage the reliability of the electric grid and efficient market operations.

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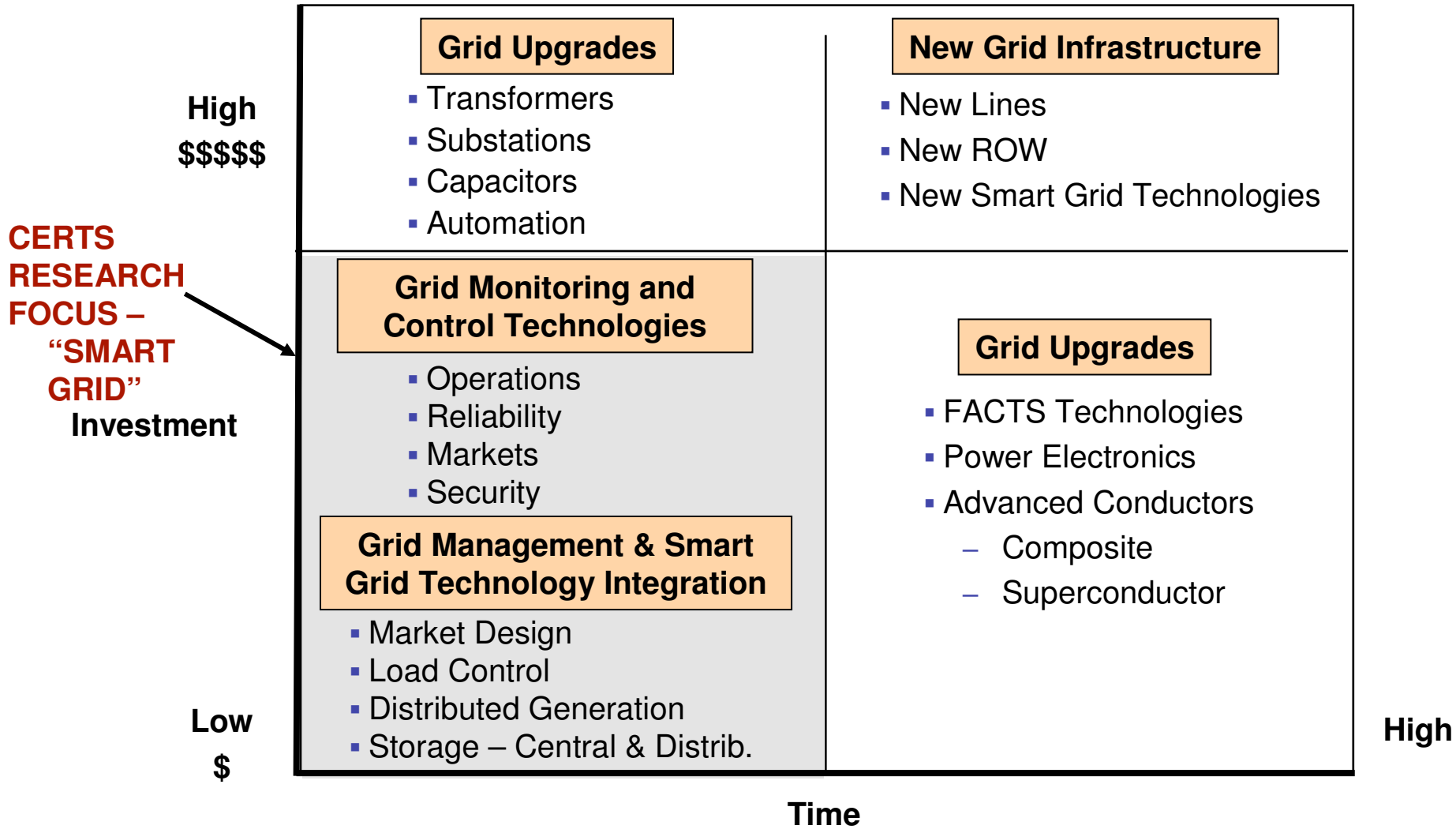
Grid Solutions Framework and CERTS Research Focus

Grid Solutions Framework



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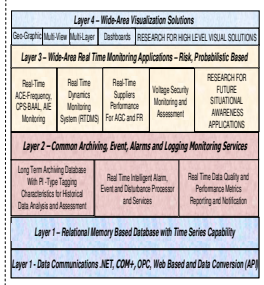
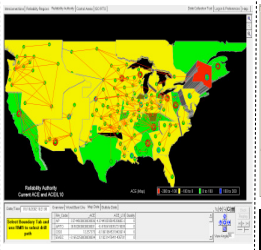
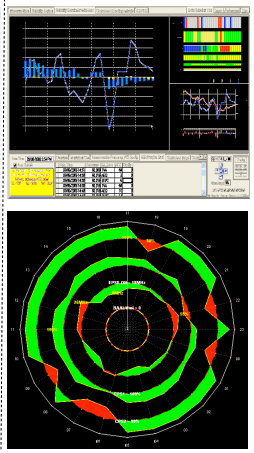
Research Focus 1:
Reliability Metrics and Compliance Monitoring Tools

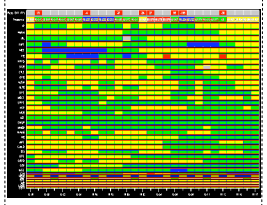
Visualization, Compliance, Monitoring, Infrastructure, Real Time Wide-Area Standards Compliance and Situational Awareness

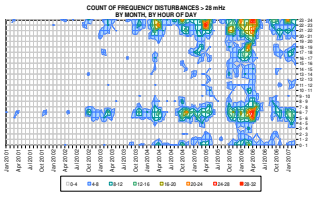
PROBLEM IDENTIFICATION	INFRASTRUCTURE DESIGN	VISUAL-IZATION	WIDE-AREA MONITORING	FORENSIC ANALYSIS	COMPLIANCE MONITORING
• 1999 Low Frequency Events on Eastern Interconnection • Declining System Performance • Frequency Excursions	▪ Wide-area visualization infrastructure • Relational time-series database	▪ Wide-area real time ACE-Frequency monitoring tool • Suppliers performance for AGC and frequency response	▪ Interchange Error (AIE) Monitoring • Wide-area Inadvertent Monitoring	▪ Performance standards research, validation, field trials • Resources adequacy load-generation analysis and assessment	▪ CPS-BAAL monitoring and analysis • Research for situational awareness for resource adequacy

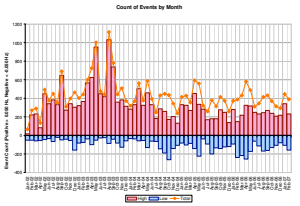












GOAL

Common Wide-Area, Real Time Monitoring Platform – Standards Compliance, Key Metrics for Reliability Intelligent Alarms, Reports, and Event Analysis Situation Awareness Visualization Dashboards for NERC, DOE, and FERC

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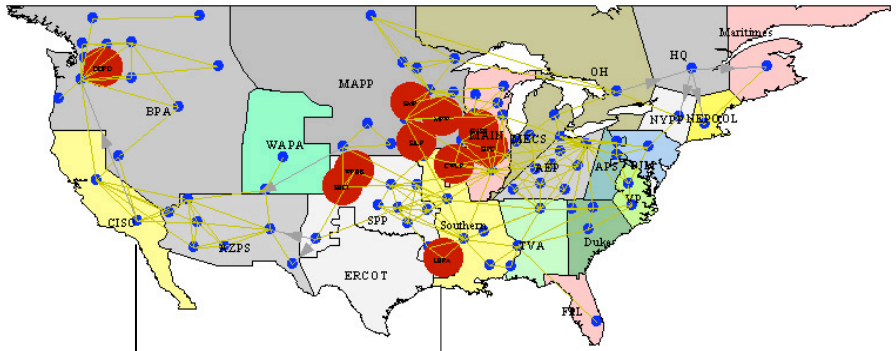
Applications Architecture

(1) DATA ACQUISITION

123 CONTROL AREAS SEND DATA THROUGH NERC-NET

- **DATA COLLECTED AT NERC ICCP AND CONCENTRATED IN DATABASE SERVER**
- **DATA PROCESSED FOR NERC-CERTS WIDE-AREA REAL TIME APPLICATIONS**



NERC Secure, Redundant Database Server

NERC Ethernet (Princeton)

NERC Applications And Web Server

REAL TIME MONITORING DATA BROADCAST OVER INTERNET-EVERY 60 SECONDS

Reliability Coordinators And Other Applications Users

Early Alarms Notification

(2) DATA VALIDATION AND ARCHIVING AT PRINCETON

(3) INTELLIGENT REAL TIME ALERTS AND ALARMS

(4) MONITORING AND TRACKING USING MULTI-VIEW GEO-GRAPHIC WIDE-AREA G3P VISUALIZATION

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Typical Use for Root Cause Identification – ACE-Frequency Application

A

Act on Early Warning Intelligent Alarms

Subject Line

High Frequency Trigger Limit Violation 60.055 Hz

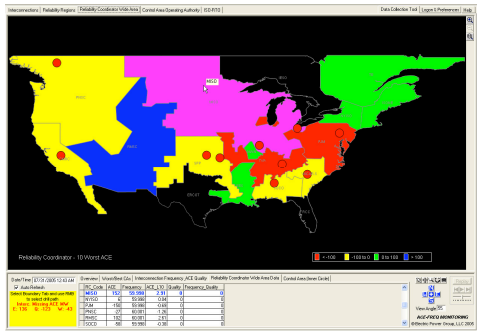
Message

FTL HIGH: -EAST 8/23/2005 11:34:00 PM (EDT)
Frequency has reached/or exceeded FTL of 60.05 Hz.
for more than 5 minutes.

Load-Generation resources under inadequate balance.

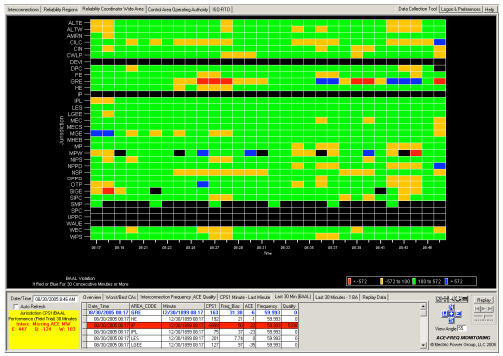
B

Select Jurisdiction (s) Violating Performance Metric Threshold Now



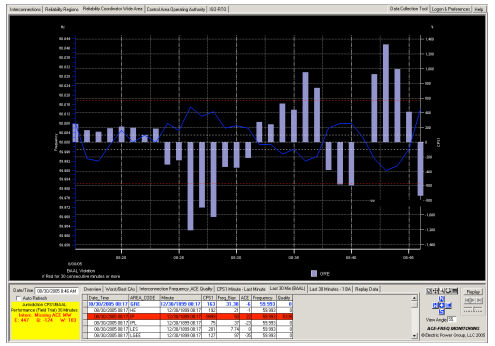
C

Identify Control Areas Contributing to Jurisdiction Violation Now in Last 30-Minutes



D

Zoom-In and Evaluate Magnitude and Duration of Problem For Worst Control Areas



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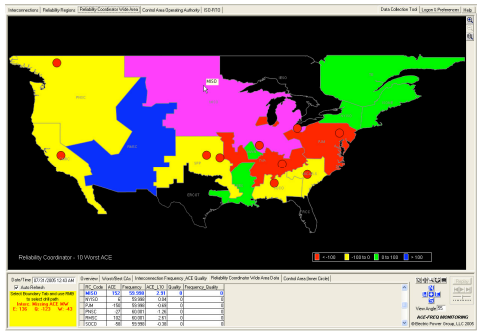

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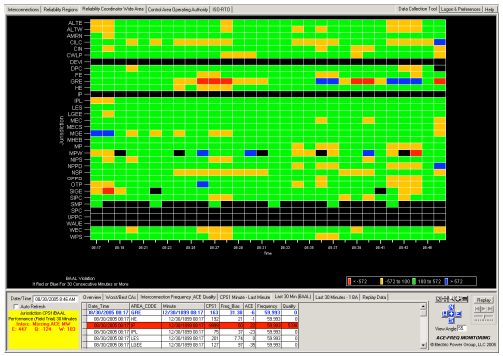

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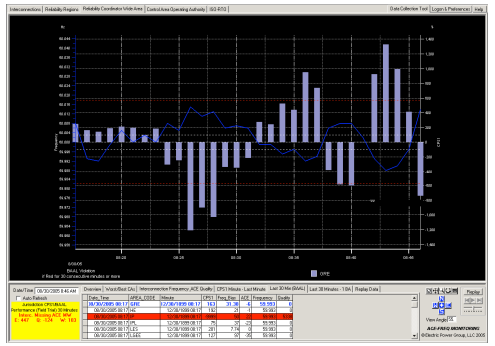

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Research Focus 2:
North American SynchroPhasor Initiative

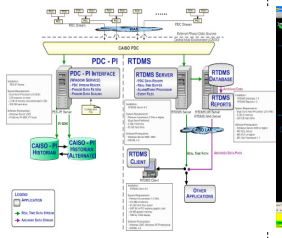
Phasor Measurements, Real Time Wide-Area Situational Awareness, Visualization, Infrastructure, Monitoring, Alarming, and Control

PROBLEM IDENTIFICATION

- 1996 Western Interconnection Blackouts
- 2003 Northeast Blackout

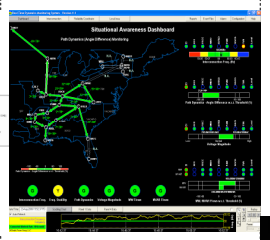
INFRASTRUCTURE DEVELOPMENT

- TVA Super PDC
- IEEE 37.118
- NIST SynchroLab



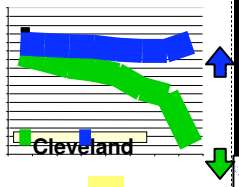
VISUALIZATION FOR WIDE-AREA SITUATIONAL AWARENESS

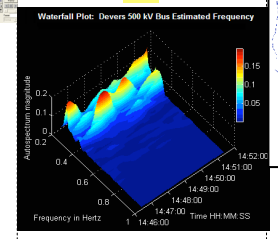
- Real Time Dynamics Monitoring System



FORENSIC ANALYSIS/ BASELINING

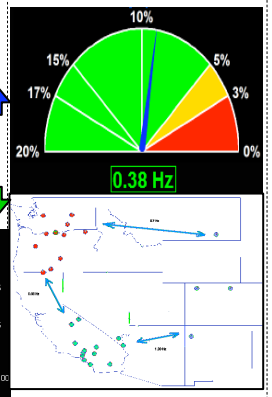
- CAISO Operating Engineers Workstation
- Baselining Static Angles in East





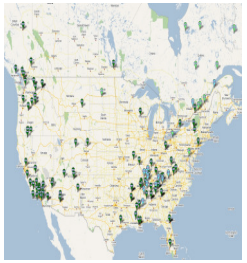
APPLICATIONS

- Small Signal Stability Monitoring
- Intelligent Alarming
- State Estimation
- Adaptive Islands



INDUSTRY ADOPTION

- EIPP -> NASPI
- WECC WAMTF
- Research Roadmap



GOAL

Industry Approach to Phasor Technology Research and Applications:

- Visualization
- State Estimation
- Mode Monitoring
- Alarming
- Real Time Controls

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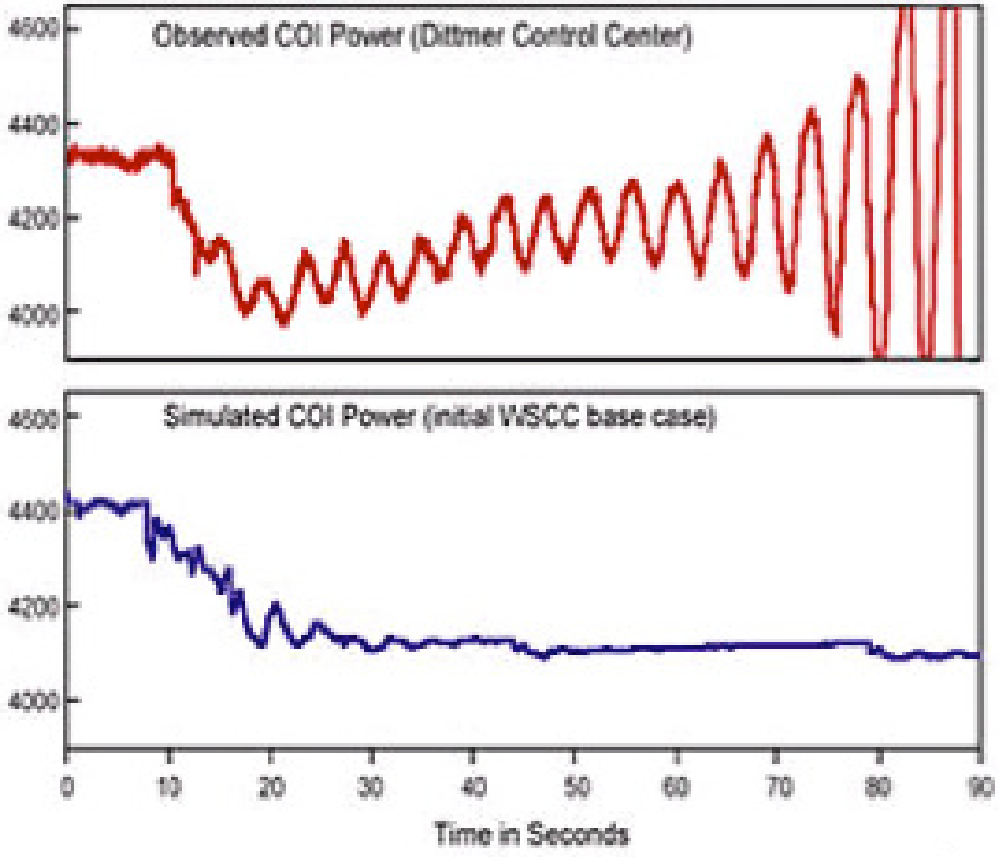
Inaccurate Dynamic Models were a Cause of the WECC 1996 Breakup

Actual System Performance

- unstable system behavior observed.



Model Simulation

- predicted stable system performance.

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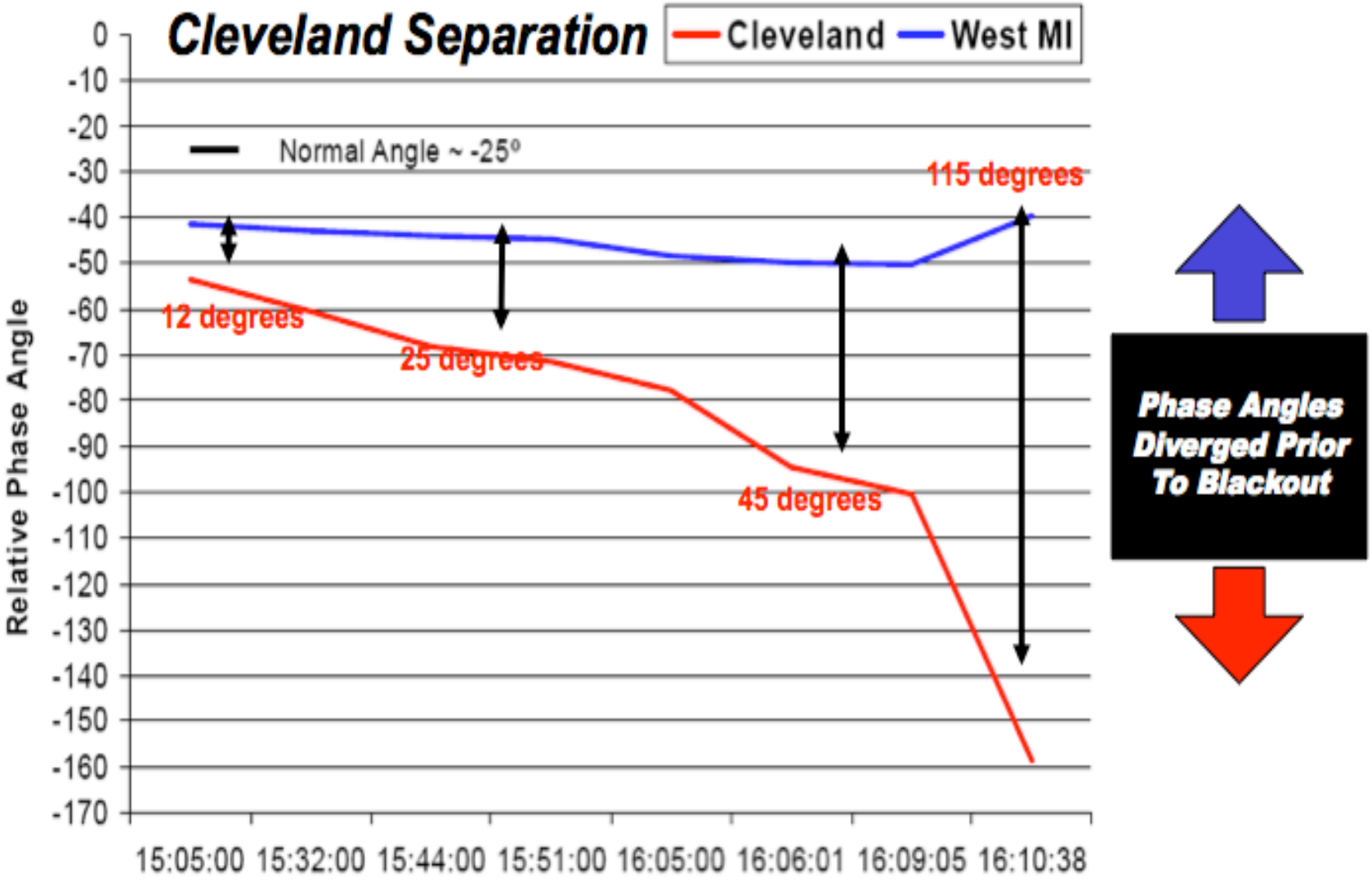
Lack of Wide-Area Visibility Was a Cause of the El Aug 14th, 2003 Blackout



Source: www.nerc.com
Angles are based on data from blackout analysis.
Angle reference is Browns Ferry.

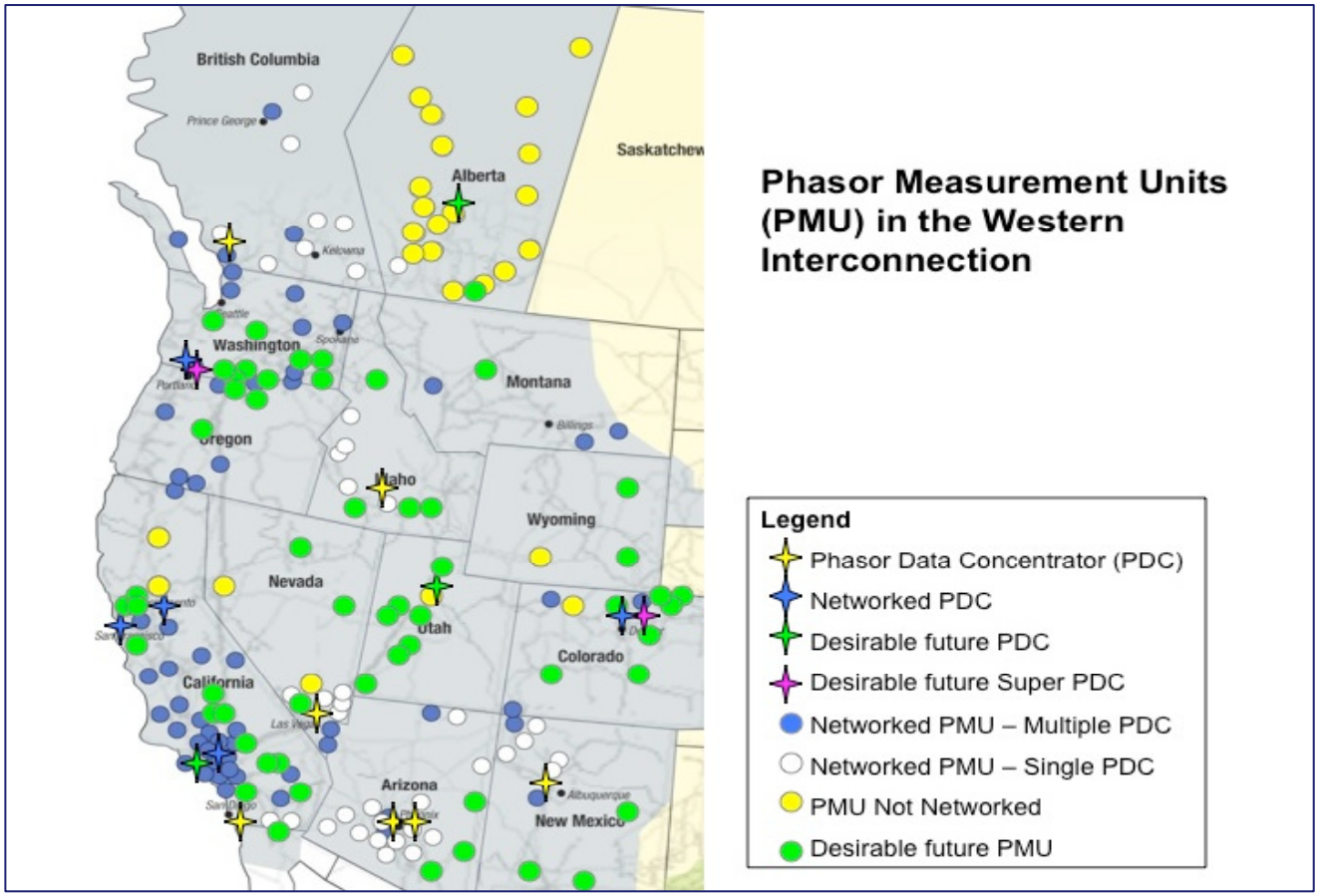
Phasor Technologies Give Operators *MRI-like* Visibility of Power Systems

ATTRIBUTE	Traditional Grid Monitoring (SCADA)	PHASOR Technologies
Resolution	1 sample every 2-4 seconds	10-120 samples per second
Measured Quantities	Magnitude Only	Magnitude & Phase Angle
Time Synchronization	No	Yes
Focus	Control Area (Local) monitoring & control	Wide area (interconnection) monitoring & control
Observability	Steady state only	Steady state, dynamic and transients
Monitoring Angles, Damping, Frequency Response, & Other Metrics	No	Yes
Oscillation Detection	No	Yes

Phasor technology is *NOT* a replacement for SCADA, rather it *complements* existing SCADA systems

WESTERN INTERCONNECTION – EXISTING PMUs – NEW & PROPOSED PMUs

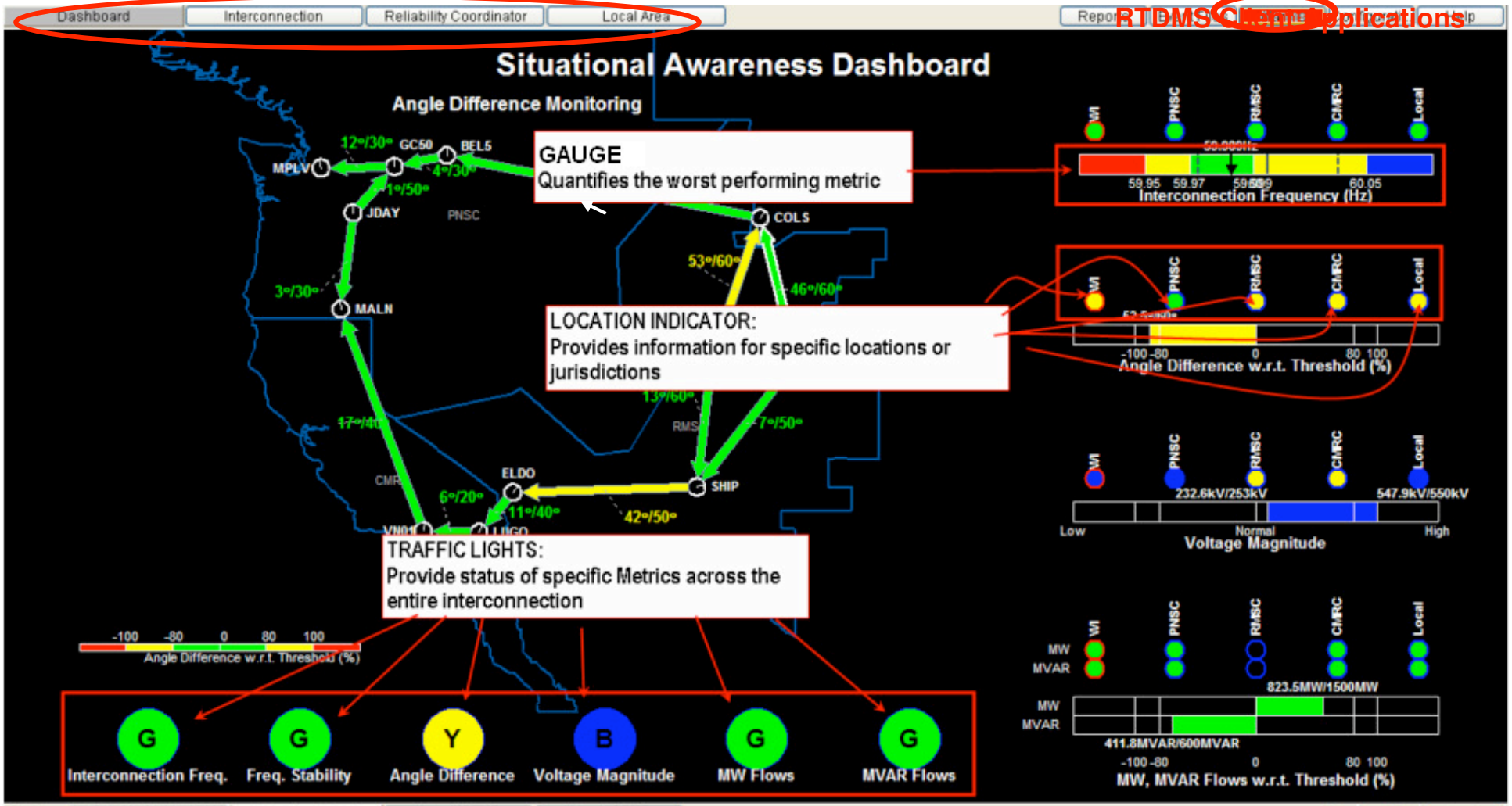
GOAL – ALL 500 KV SUBSTATIONS, RENEWABLES AND KNOWN CONGESTION POINTS



Visualization – "Dashboard" Display

Visualization Tiers – Dashboard, Interconnection, Reliability Coordinator, Local Area

Real Time Alarms within ALL RTDMS Client Applications



Research Focus 3:

Science-Based Analysis of Market Designs and Real-Time Market Monitoring Tools

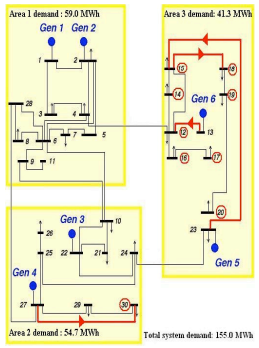
Engineering Design Tools, Market Simulation, Real-Time Market Monitoring Tools

PROBLEM IDENTIFICATION

- Eastern ISO Price Spikes 1999
- Western Market Meltdown 2000-2001

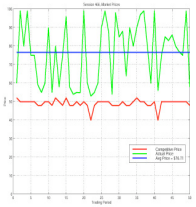
MARKET ANALYSIS INFRASTRUCTURE

- Experimental economics power system market simulation platform



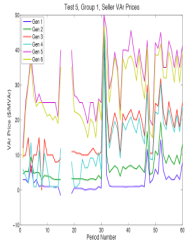
MARKET DESIGN EVALUATION

- Auction design evaluations
- Effects of demand response



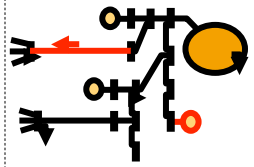
INCORPORATING NETWORK PROPERTIES

- VAR and real power markets
- Co-optimization of real and reserve power markets



MARKET MONITORING TOOLS

- Revenue sensitivity
- Real-time market monitoring prototype tool



COMPLETE OPTIMI-ZATION OF MARKET DESIGN

- Super OPF design studies

Tools that optimally dispatch and correctly price:

- Real energy
- VArs
- Real power reserves
- Dynamic reactive reserves
- Voltage

GOAL

A Complete Network Optimization Tool for Organized Markets, and Supporting Real-Time Market Monitoring Tools for Market Operators and FERC0

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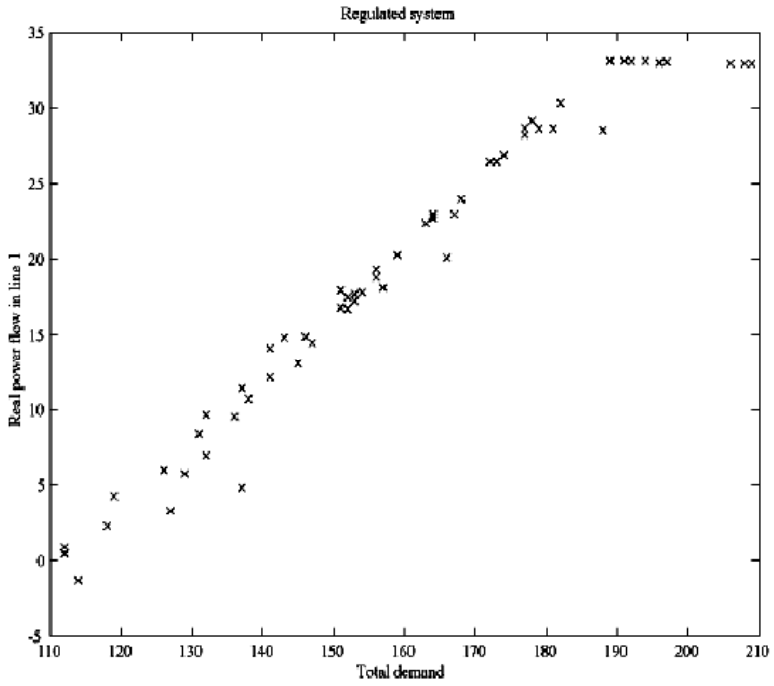
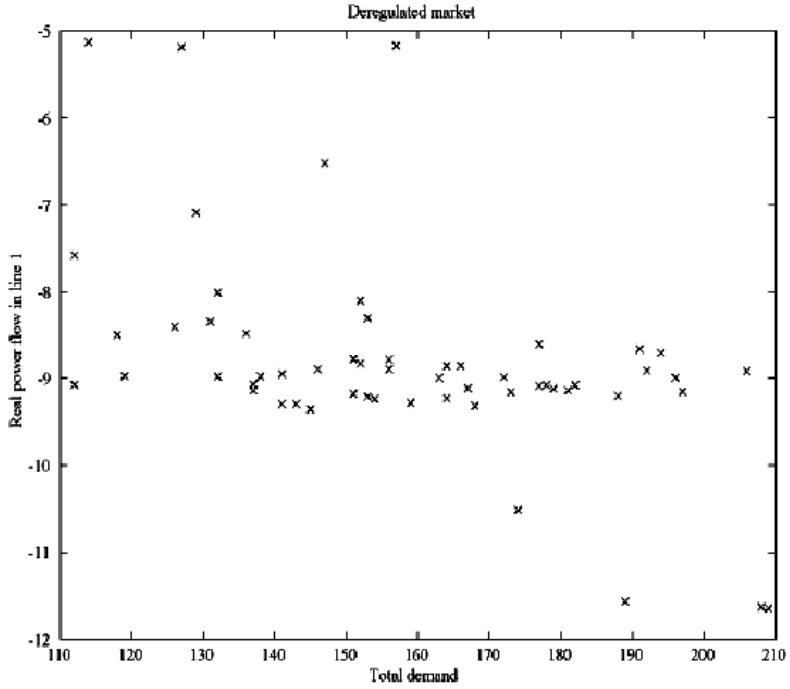
Can Operators Predict Market Behavior?

Traditional Operations



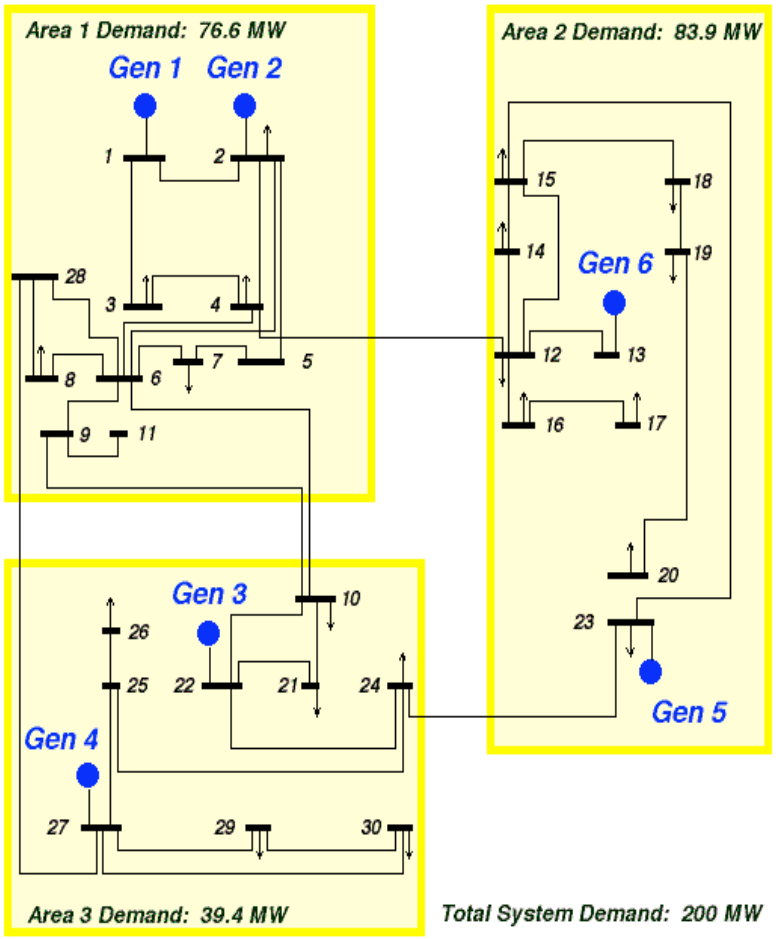
- Powerplants dispatched in order of increasing costs
- Strong correlation between power flow on lines and total electricity demand
- Reliable system operation can be scheduled in advance

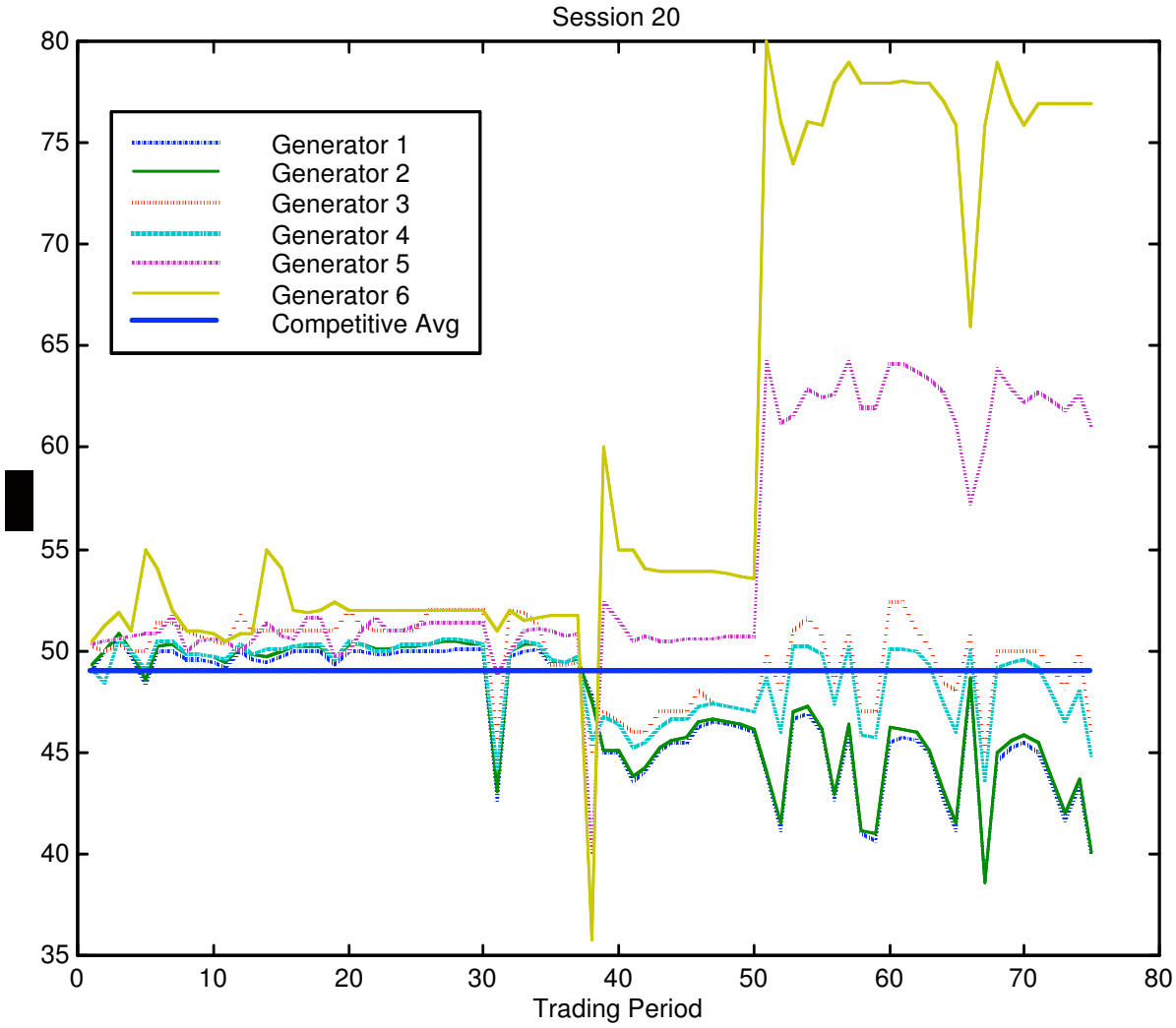
Market-based Operations



- Powerplants dispatched by market participants seeking profits
- Poor correlation between power flow on lines and total electricity demand
- Reliable system operation more difficult to schedule - requires better predictive tools

Science-Based Analysis of Electricity Market Designs and Operation





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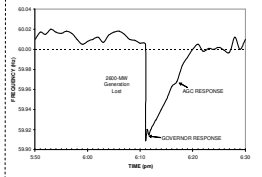
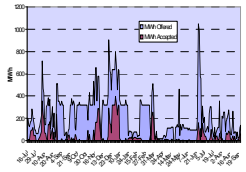
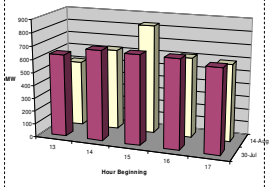
Research Focus 4:
Demand Response or Load As A Resource

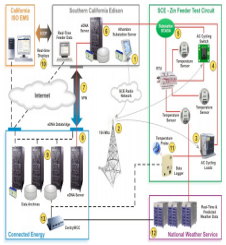
Capability Building, Demonstrations, Policy Changes, Enhanced Values

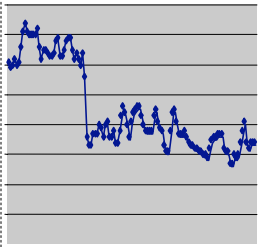
PROBLEM IDENTIFICATION	TECHNOLOGY REQUIREMENTS	TECHNICAL SUPPORT/ CAPABILITY BUILDING	DEMON-STRATIONS	INSTITUTIONAL CHANGE	EFFICIENT DEMAND-SIDE MARKET PARTICIPATION
• Price Spikes • Supplier Market Power • Inelastic Demand	▪ Technology review ▪ Ancillary services review	▪ Program design and evaluations for leading ISO demand response program (NYISO, ISO NE, PJM)	▪ Provision of spinning reserve with aggregated demand-side resources	▪ NERC Policy 10 revisions to allow for demand response ▪ WECC CMOPS and MORCWG policy changes	▪ Quantify unique system values of Demand Response – speed of response, geographic targeting ▪ Market power mitigation











GOAL

Meaningful Demand-Side Participation in Competitive Wholesale Markets for Energy and Ancillary Services

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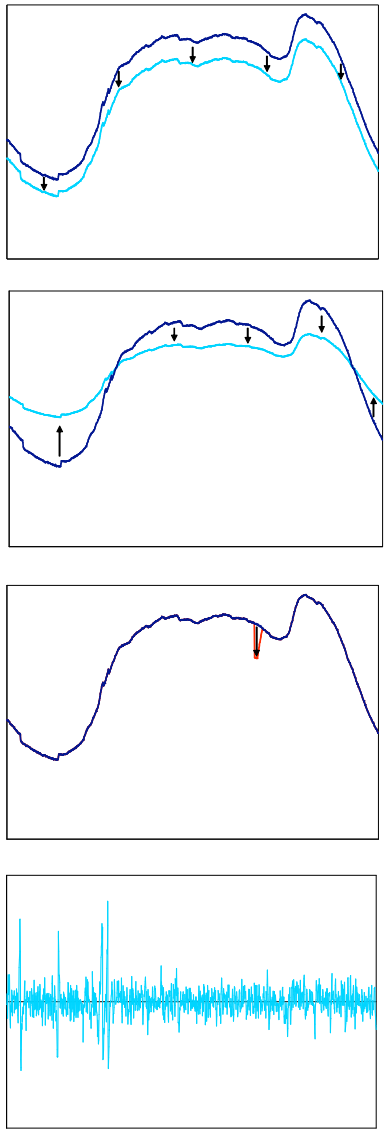
There Are Five Basic Types of Responsive Load

1. **Energy Efficiency** programs reduce overall electricity consumption, generally also at times of peak demand
2. **Price Response** programs move consumption from times of high prices to times of lower prices (real time pricing or time of use)
3. **Peak Shaving** programs require more response during peak hours and focus on reducing peaks on high-system load days
4. **Reliability Response** (contingency response) requires the fastest, shortest duration response. Response is only required during power system "events." – This is new and slowly developing.
5. **Regulation Response** continuously follows minute-to-minute commands from the grid in order to balance the aggregate system load and generation – This is also very new and appears to be very promising for certain loads.



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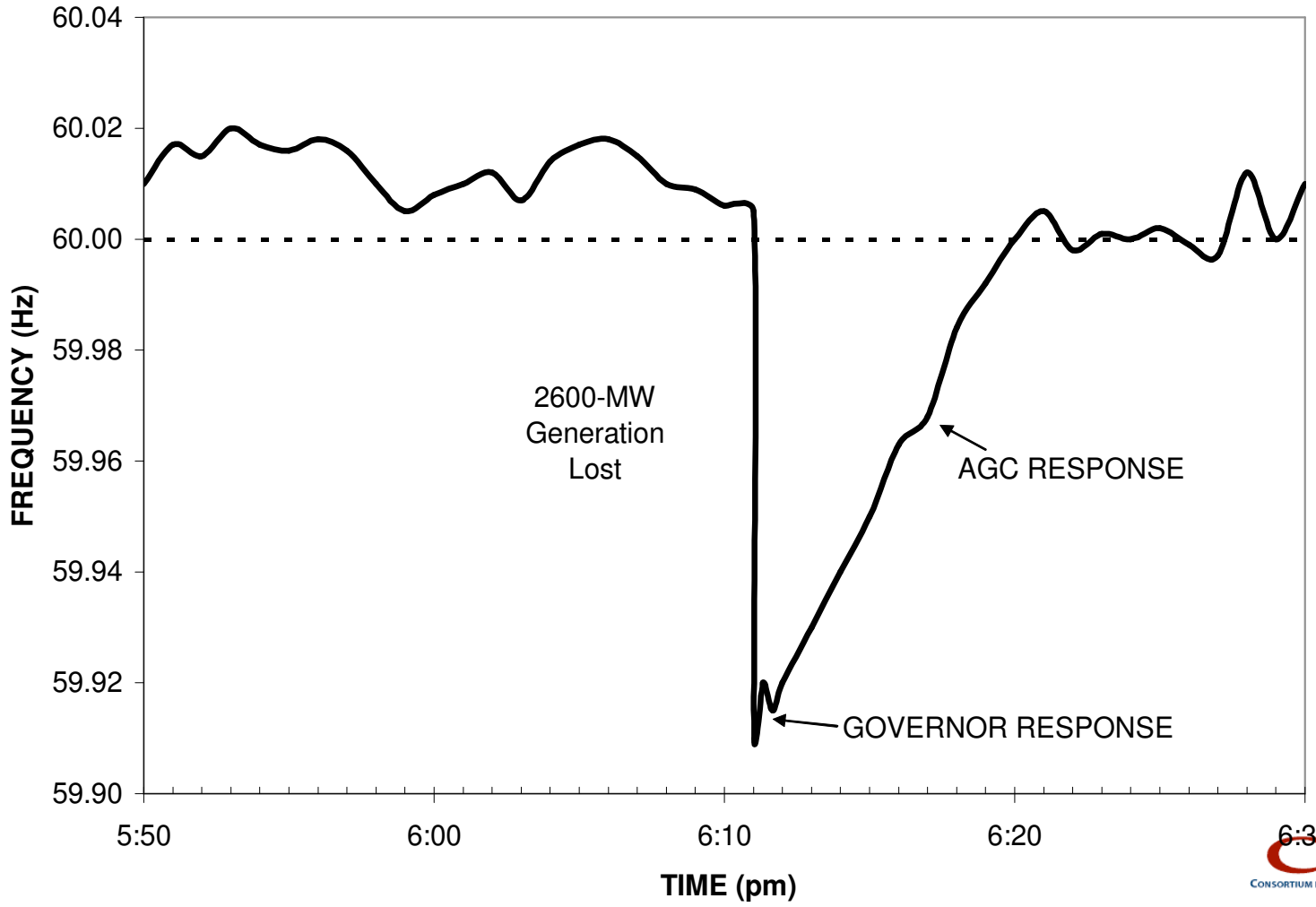
Contingency Reserves Restore System Frequency Immediately After Loss of Generation



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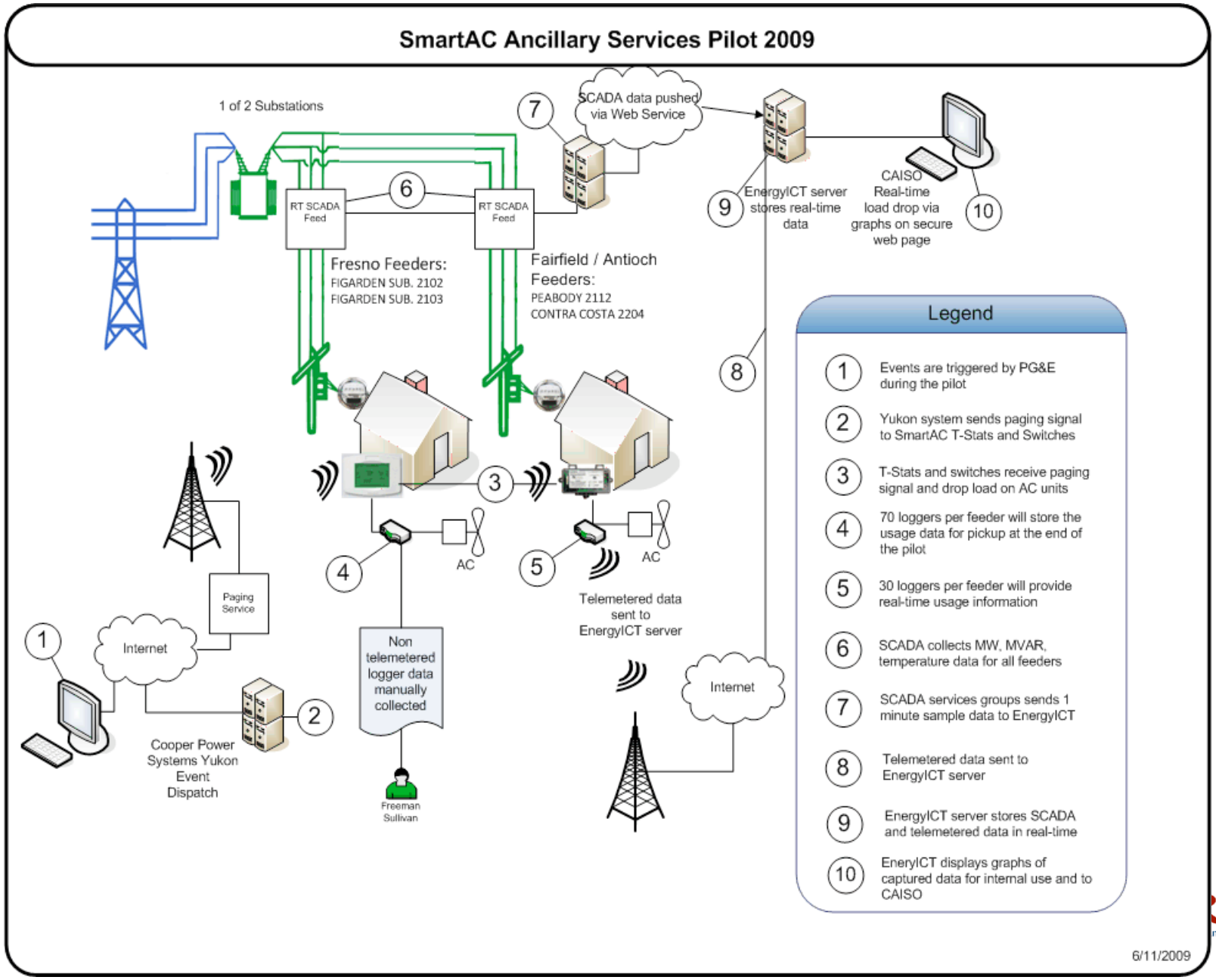
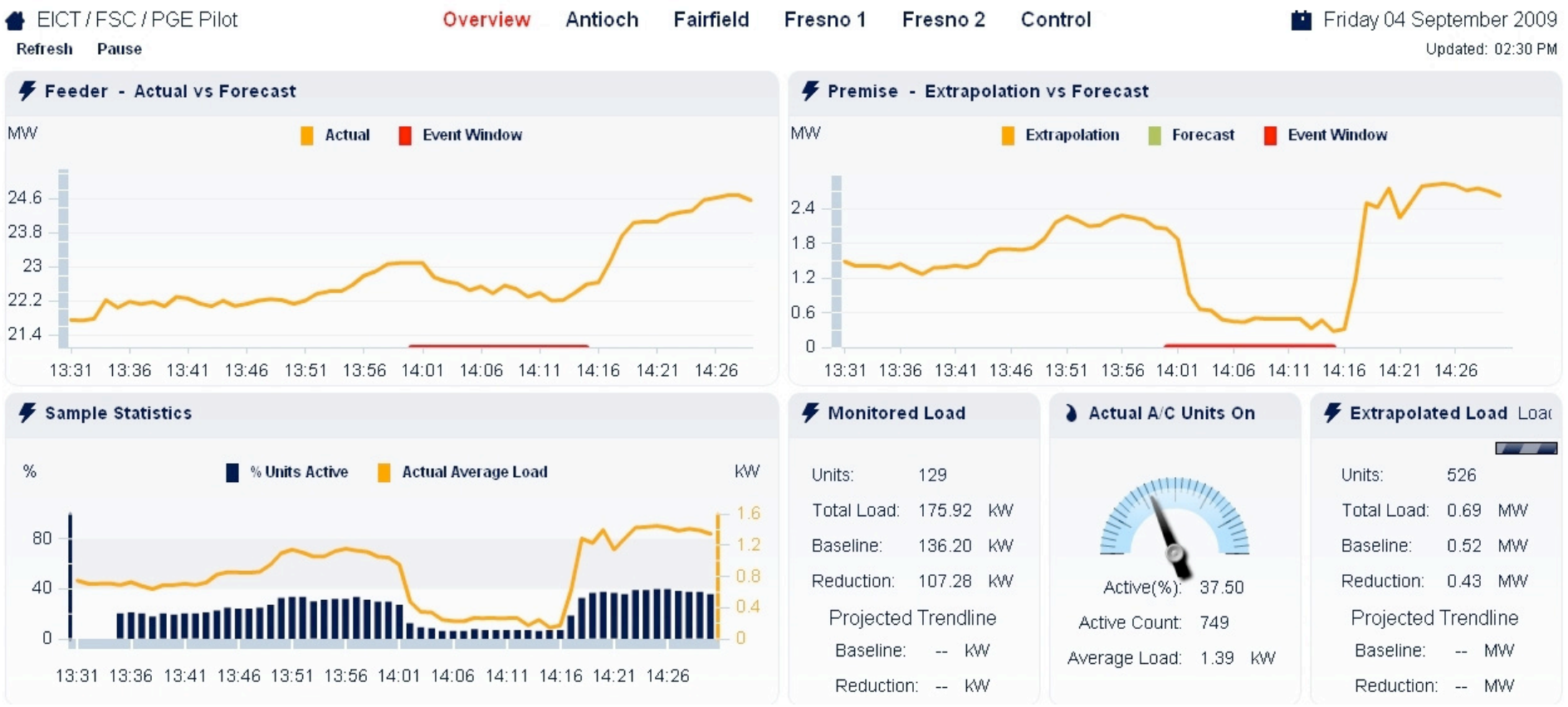
2009 PG&E Test System



PG&E Real Time Display



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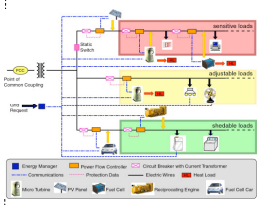
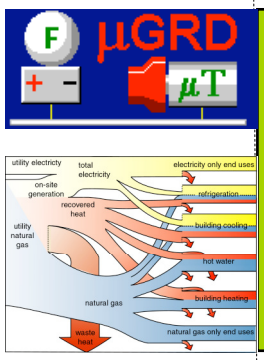
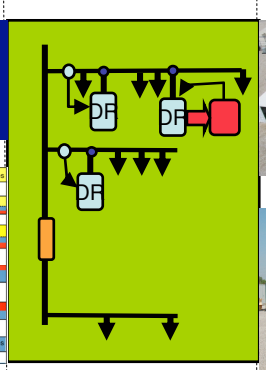
Research Focus 5:
Distributed Energy Resource Microgrids

Tool Development, Simulation, Bench-Scale Testing, Full-Scale Test Bed, and Value Engineering

PROBLEM IDENTIFICATION	CONCEPTUAL DESIGN	ANALYTIC TOOL DEVELOPMENT	PROOF OF CONCEPT	FULL-SCALE TEST BED	STANDARDIZED ENGINEERING DESIGNS
• Customer demand for reliability and power quality • Grid integration concerns	Microgrid Concept	▪ muGrid ▪ DER-Customer Adoption Model	▪ Simulation analysis ▪ Laboratory bench-scale tests ▪ Test bed design	▪ American Electric Power Test Bed ▪ IEEE 1547.4	Lower cost of key components







GOAL

A Peer-to-Peer, Plug-and-Play Design That Minimizes Custom Engineering and Presents Clusters of DER to Grid as Controllable Loads – Good and Model Citizens of the Grid

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Microgrids vs. CERTS Microgrids

"A microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources which as an integrated system can operate in parallel with the grid or in an intentional island mode"

Microgrids Research Assessment prepared by Navigant Consulting for DOE and CEC. May 2006

Distinguishing features of the **CERTS Microgrid *Concept***

- Seamless islanding and reconnection via single PCC
- Peer-to-peer, autonomous coordination among micro-sources
- Plug-and-play - no custom engineering

Distinguishing features of the **CERTS Microgrid *Test Bed Demonstration***

- Small sources (<100 kW each)
- No stand-alone storage (yet)
- No power flow onto the grid

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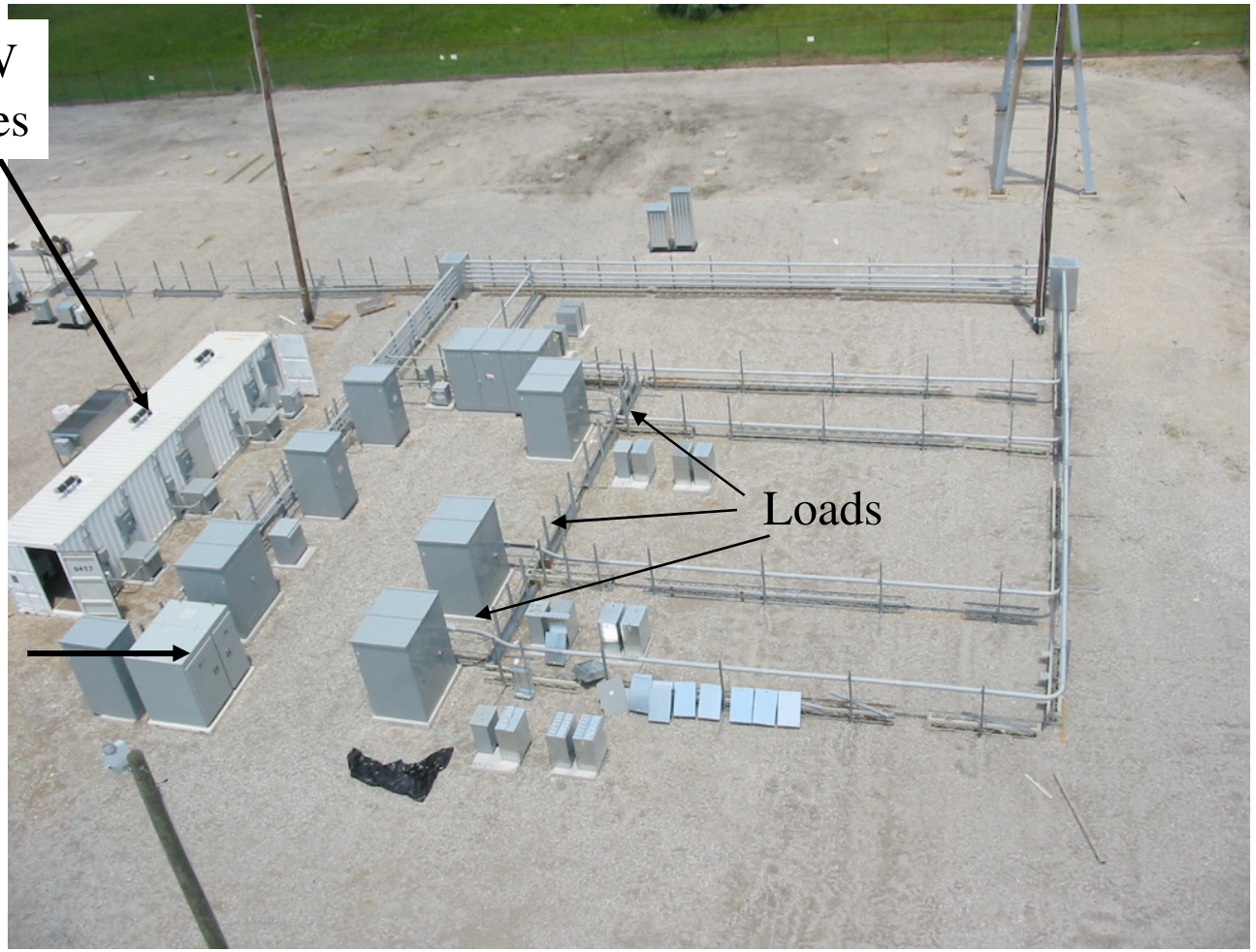
AEP/CERTS Microgrid test site

60 kW Sources

Static Switch



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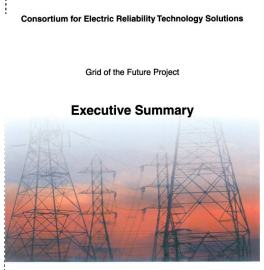
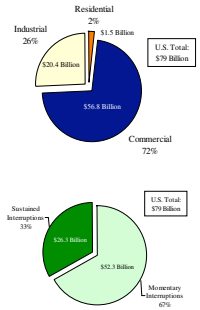
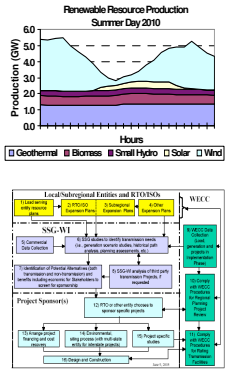
Research Focus 6:
Reliability Technology Issues and Needs Assessment

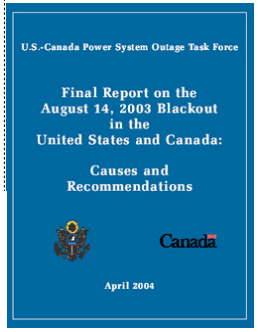
Technology Scoping, Analytical Studies, DOE Analysis Support

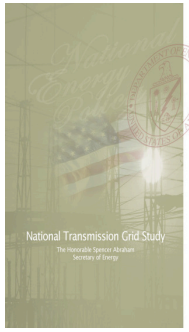
PROBLEM IDENTIFICATION	TECHNOLOGY SCOPING	ECONOMIC ASSESSMENT	TECHNICAL ASSESSMENT	BLACKOUT INVESTIGATION	NATIONAL POLICY STUDIES
• Blackouts, Declining Reliability • Increased Transmission Congestion • Inadequate Transmission Investment	•Grid of the Future White Papers •Real-time tools assessment •Grid metrics	•Cost of power interruptions to US •Review of US congestion costs •Transmission cost allocation	• Renewable operational integration •Transmission planning R&D needs • Event reporting	• 1999 Power Outage Study Team • 2003 Blackout Investigation	• 2002 National Transmission Grid Study • 2006 and 2009 DOE Congestion Studies











GOAL

Science-based, technical analysis of reliability technology and policy issues to inform decision-makers

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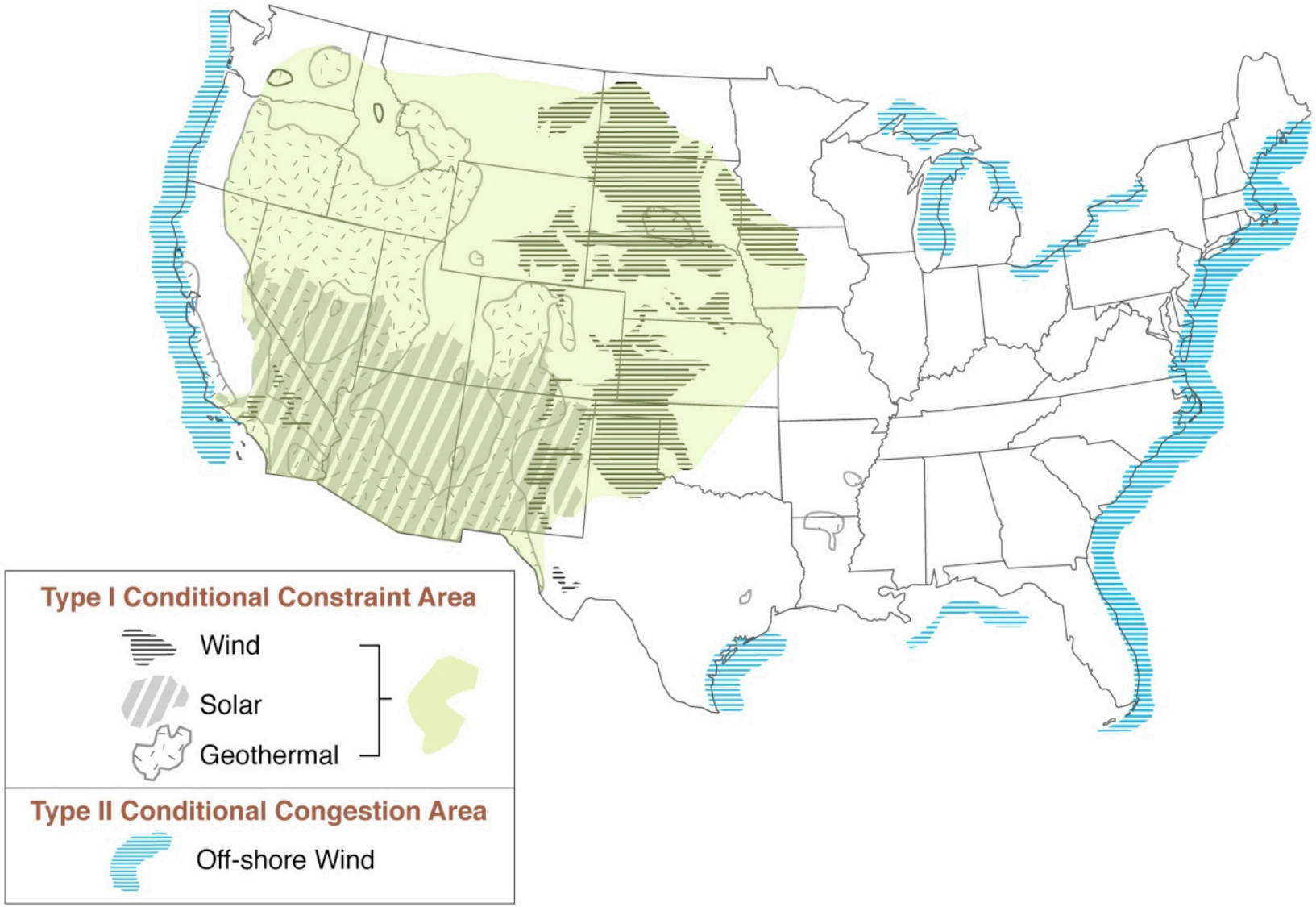
Renewable Electricity Generation Resources Are Sometimes Located Far From Load Centers



Source: DOE National Electric Transmission Congestion Study

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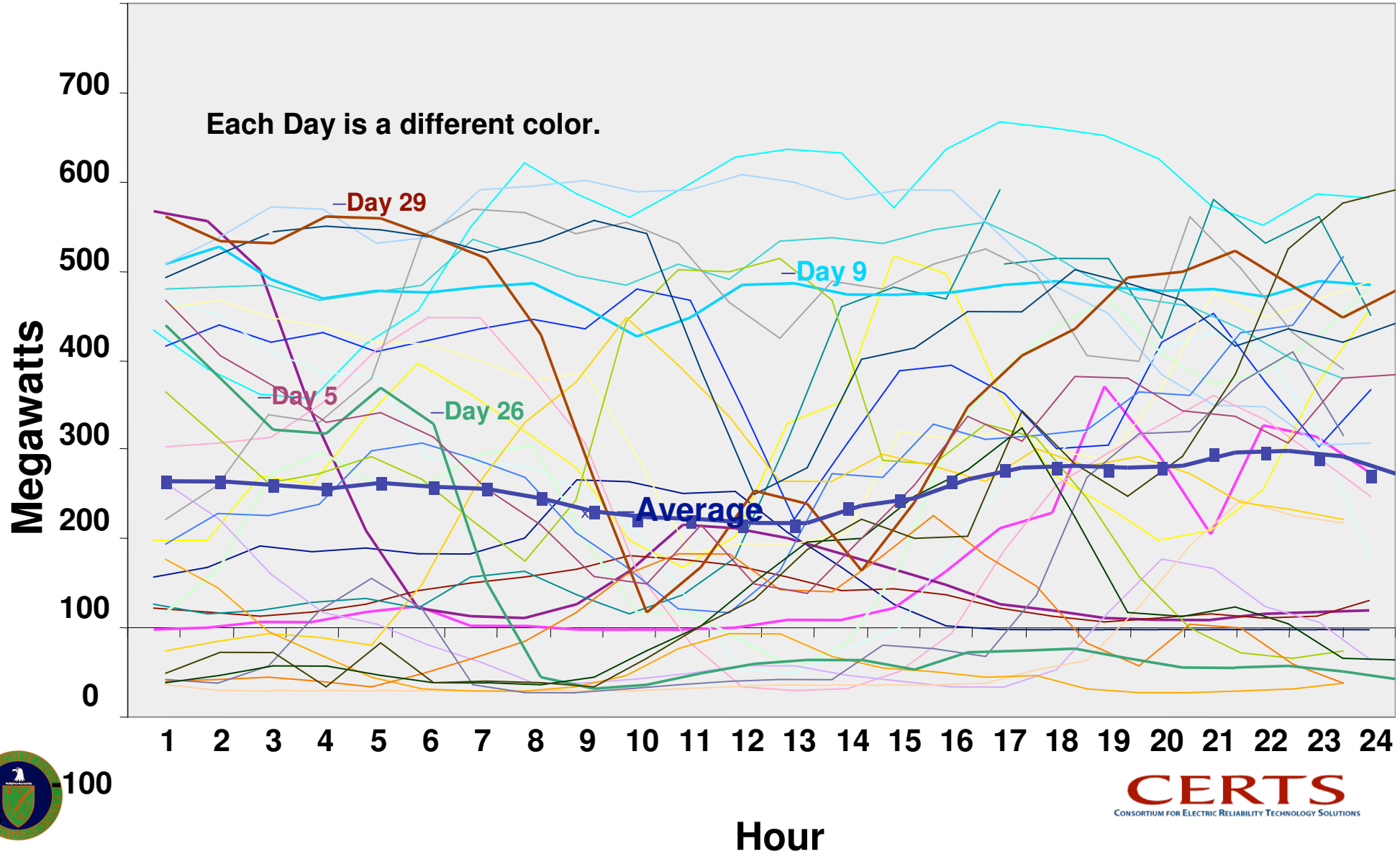
Wind is an *Intermittent* Resource; However, It Is Also a *Predictable* Resource

Tehachapi Wind Generation in April – 2005 Source: CAISO



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